**E**astern **M**editerranean **U**niversity
**D**epartment of **M**echanical **E**ngineering
**L**aboratory **H**andout

## COURSE: HEAT TRANSFER (MENG 345)

**Semester:** Spring (2019-2020)

**Name of Experiment:** Combined Forced Convection and Radiation

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Submitted by:

Student No:

Date of experiment:

Date of submission:

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## EVALUATION

| | | |
|---|---|---|
| **Activity During Experiment & Procedure** | **30 %** | |
| **Data , Results & Graphs** | **35 %** | |
| **Discussion, Conclusion & Answer to Questions** | **30 %** | |
| **Neat and tidy report writing** | **5 %** | |
| **Overall Mark** | | |

**Name of evaluator:**

**Objective**

To determine the effect of forced convection on heat transfer from the surface of a cylinder at varying air velocities and surface temperatures.

To demonstrate the relationship between air velocity and surface temperature for a cylinder subjected to forced convection.

**Method**

By measuring the temperature on the surface of a horizontal cylinder subjected to heat loss by radiation and forced convection in combination then comparing the results with those obtained from a theoretical analysis.

**Equipment Required**

HT10XC Computer Compatible Heat Transfer Service Unit

HT14 Combined Convection and Radiation Accessory

**Equipment set-up**

Before proceeding with the exercise ensure that the equipment has been prepared as follows:

Locate the HT14C Combined Convection and Radiation accessory alongside the HTlOXC Heat Transfer Service Unit on a suitable bench.

Ensure that the horizontal cylinder is located at the top of the metal duct with the thermocouple located on the side of the cylinder (the cylinder can be rotated by releasing the thumb screw on the top of the mounting arrangement.

Ensure that the thumb screw is securely tightened after adjustment).

Connect the thermocouple attached to the heated cylinder to socket T10 on the front of the service unit.

Connect the thermocouple located in the vertical duct to socket T9 on the service unit.

Set the manual/remote selector switch on the console to MANUAL.

Set the VOLTAGE CONTROL potentiometer to minimum (anticlockwise) and the selector switch to MANUAL then connect the power lead from the heated cylinder on HTI4C to the socket marked Output 2 at the rear of the service unit.

Ensure that the service unit is connected to an electrical supply.

If using the HT14C software, check that the HT1OXC console is connected to the PC via the USB socket, ensure that the manual/remote selector switch on the console is set to REMOTE. and run the HT14C software Exercise C. If operating the accessory manually then leave the console selector switch set to MANUAL.
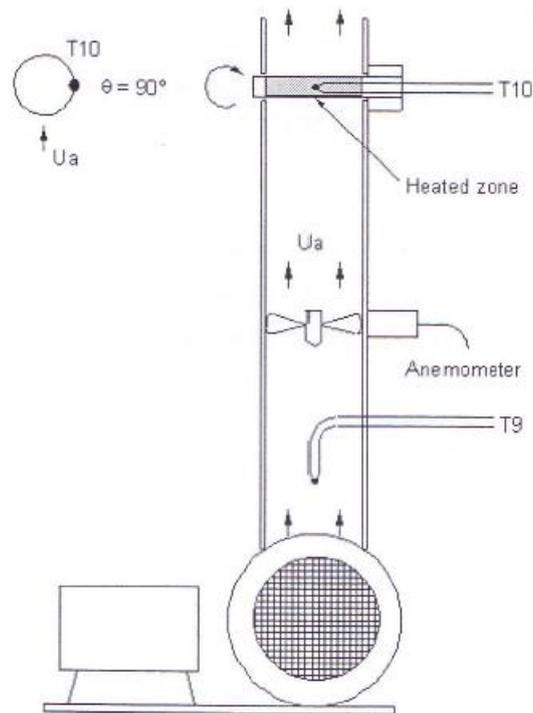
connect the mains lead from the fan (terminated at the connection box alongside the fan) to the socket marked output I at the rear of the HTIOX service unit.

Connect the lead from the anemometer in the vertical duct to the socket marked Ua on the front of the HTl0X service unit.

Ensure that the service unit is connected to an electrical supply.

**Theory/Background**

In free/natural convection the heat transfer rate from a surface is limited by the small movements of air which are generated by changes in the density of the air as the air is heated by the surface. In forced convection the air movement can be greatly increased resulting in improved heat transfer rate from a surface. Therefore a surface subjected to forced convection will have a lower surface temperature than the same surface subjected to free convection, for the same power input. If a surface, at a temperature above that of its surroundings, is located in moving air at the same temperature as the surroundings then heat will be transferred from the surface to the air and the surroundings. This transfer of heat will be a combination of forced convection to the air (heat is transferred to the air passing the surface) and radiation to the surroundings. A horizontal cylinder is used in this exercise to provide a simple shape from which the heat transfer can be calculated.

**Note:** Heat loss due to conduction is minimized by the design of the equipment and measurements mid-way along the heated section of the cylinder can be assumed to be unaffected by conduction at the ends of the cylinder. Heat loss by conduction would normally be included in the analysis of a real application.

| | |
|---|---|
| Total heat loss from the cylinder | $Q_{tot} = Q_{fm} + Q_{rm}$ |
| Heat loss due to forced convection | $Q_c = h_C A (T_s - T_a)$ |
| Heat loss due to radiation | $Q_r = h_r A (T_s - T_a)$ |
| Heat transfer area | $A = \pi D L$ |

The heat transfer coefficients $Hf_m$ due to forced convection and $Hr_m$ due to radiation can be calculated using the following relationships:

$$h_r = \sigma \varepsilon \frac{(T_s^4 - T_a^4)}{(T_s - T_a)} \qquad (\frac{W}{m^2.K})$$

where:

$\sigma$ = Stefan Boltzmann constant ($\sigma = 5.67 \times 10^{-8} \frac{W}{m^2.K^4}$)

$\varepsilon$ = Emissivity of surface = 0.9

Ts = Surface temperature of cylinder (K)

Ta = Ambient temperature (K)

$$h_c = \frac{k}{D} Nu \qquad (\frac{W}{m^2.K})$$

where:

k = conductivity of the air ($\frac{W}{m.K}$)

D = diameter of the cylinder (m)

Nu = Average Nusselt number (dimensionless)

An empirical formula can be used to calculate the value for Nu as follows:

$$Nu = 0.3 + \frac{(0.62Re^{0.5}Pr^{0.33})}{\left[1 + \left(\frac{0.4}{Pr}\right)^{0.66}\right]^{0.25}} \left[1 + \left(\frac{Re}{282000}\right)^{\frac{5}{8}}\right]^{\frac{4}{5}}$$

From SW Churchill and M Bernstein "A correlating Equation for Forced convection from Gases and Liquids to a circular cylinder in crossflow". Journal of Heat Transfer, 99:300-306 (1977).

Where:

Re = Reynolds number = Uc D /v (dimensionless)

Pr = Prandtl number for air (dimensionless)

Uc = Corrected air velocity (m/s)

Corrected air velocity Uc = 1 .22Ua (m/s)

(The cylinder causes a blockage in the duct resulting in a local increase in the air velocity.)

Values for k, v and Pr depend on the temperature of the air and can be found using the table included in the HT14C teaching manual.

The actual power supplied to the heated cylinder $Q_{in}$ = V I (W)

**Procedure**

Refer to the operation section (page 3-1) if you need details of the instrumentation and how to operate it.

Switch on the front Mains switch (if the panel meters do not illuminate check the RCD at the rear of the service unit, the switch should be up).

If controlling the accessory manually using the console then set the upper selector switch on HT1OXC to position Ua to indicate the air velocity in the duct.

Start the centrifugal fan by pressing the switch on the connection box.

Set the fan to give an air flow rate of 0.5 m/s. If using the software then the fan speed may be set using the control box on the mimic diagram screen. If operating the accessory manually then the fan speed may be adjusted using the AUXILIARY CONTROL knob to give a reading of 0.5 m/s on the top panel meter with the selector switch set to m/s.

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**NOTE for HT14 Users:**

If using the HT14 accessory instead of the HTI4C, the air velocity is by manually rotating the disc in front of the fan. The fan on the HT14 may not be operated using the console or the software.

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Set the Heater Voltage to 15 volts. If using the software then the heater may be controlled using the control box on the mimic diagram screen. If operating the accessory manually using the HTl0XC console then adjust the VOLTAGE CONTROL potentiometer to give a reading of 15 Volts on the top panel meter with the selector switch set to position V.

Allow the HT14C to stabilize. If using the software then monitor the temperature T10 on the mimic diagram screen. If operating the accessory manually then monitor the surface temperature of the cylinder T10 using the lower selector switch/meter on the HTl0XC console.

When the temperatures are stable select the GO icon on the top toolbar to record the following: Ua, T9, T10, V, L.

If operating the accessory manually then record these values from the HT1OXC console using the display meters/switches to select each required value.

Adjust the fan to give an air velocity of 1.0 m/s.

If using the software then select the icon to create a new results table.

Allow the HT14C to stabilize then repeat the above readings.

Repeat the above procedure for air velocities of 2.0 m/s and 3.0 m/s.

**Results and Calculations**

For this exercise the raw data is tabulated under the following headings:

| | | |
|---|---|---|
| Heater Voltage | V | Volts |
| Heater Current | I | Amps |
| Upstream air temperature | T9 | (°C) |
| Surface temperature of cylinder | T10 | (°C) |
| Air velocity in the duct | Ua | (m/s) |

You should also estimate and record the experimental errors for these measurements.

For this exercise the following constants are applicable:

Diameter of cylinder d = 0.01 (m)
Length of cylinder L = 0.07 (m)

For each set of readings, the derived results are tabulated under the following headings:

Heat flow (Power to heater) $Q_{in} =$ (Watts)

Heat transfer area A, = (m2)

Heat transfer coefficient (forced convection) $h_c = (\frac{W}{m^2.K}))$

Heat transfer coefficient (radiation) $h_r = (\frac{W}{m^2.K}))$

Heat transfer by natural convection $Q_c =$ (W)

Heat transfer by radiation $Q_r =$ (W)

Total heat transferred $Q_{tot} =$ (W)

Estimate the cumulative influence of the experimental errors on your calculated values for $U_c$, $A_s$, $h_c$, $h_r$, $Q_f$, $Q_r$, $Q_{tot}$ and measured values for Ua, T9, T10, L and x.

Compare the theoretical value obtained for $Q_{tot}$ with the measured value for $Q_{in}$ and explain any difference in the two values.

Compare the calculated heat transfer due to forced convection $Q_f$ and radiation $Q_r$.

Plot a graph of surface temperature T10 against corrected air velocity Uc. Your graph should be similar to the diagram below:

Observe that the surface temperature of the cylinder reduces as the air velocity increases for a
fixed heat input $Q_{in}$.
Observe that the surface temperature reduces more rapidly at low air velocities
and reduces more slowly at high air velocities.
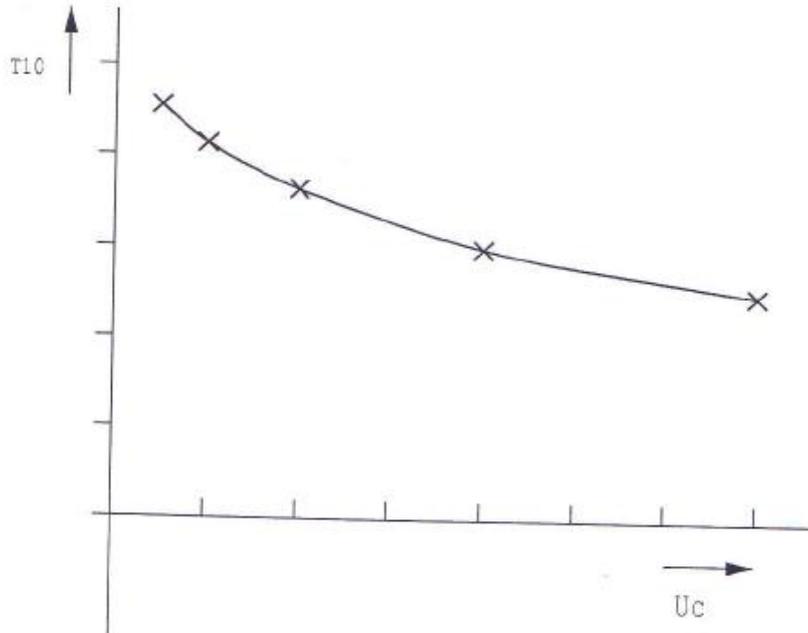


**Conclusions**

You have demonstrated how the heat transfer from a heated surface to its surroundings is a
combination of forced convection and radiation (the effect of conduction must also be included
where relevant) when the surface is located in a moving air steam. For equilibrium, heat input to
a surface must equal the heat transferred from the surface to its surroundings. since heat transfer
from a surface increases with the velocity of the air, increased air velocity past a surface results
in a decrease in the temperature of the surface.
The calculation of the heat transfer coefficient $h_c$ for forced convection involves the use of
empirical equations which are specifically related to heat transfer from a horizontal cylinder.
Empirical equations are available for other classical shapes which will allow a theoretical
analysis to be performed. The effect of air velocity forced convection on surface temperature.

**Note:** Exercise HT14CD should be carried out on the completion of this
exercise.